MITIGATION OF THERMAL ENVIRONMENT BY A SPECIAL PAVING MATERIAL, KATSUREN TRAVERTINE

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Abstract

A special material for pavement, "Katsuren Travertine" is produced from limestone (*foraminifera* rich) mined around Katsuren Town in the Okinawa Island. One advantage of "Katsuren Travertine" as a paving material comparing with others like concrete is saving the increase of surface temperature by solar radiation. The authors have settled "Katsuren Travertine" and comparative normal concrete blocks on a flat grassland with no sunshade, and monitored surface temperature, conductive heat flux, radiation balance, and other meteorological factors. As another comparative study, the high-albedo painting which fitted a color tone and a reflection rate to "Katsuren Travertine" were applied on the surface of the concrete. The authors concluded the high reflectance and thermal physical factors like heat capacity of "Katsuren Travertine" have potential to mitigate urban thermal environment.

Key words: Travertine, heat island, pavement material, heat budget, thermal environment

勝連トラバーチン舗装工のヒートアイランド現象抑制効果の定量化研究

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特殊舗装材料である勝連トラバーチンは，有孔虫石灰岩を母材としており，沖縄本島の勝連町に多く産出する．舗装材料としての勝連トラバーチンのメリットは，コンクリートなどほかの舗装材料にくらべ，日射による表面温度の上昇が抑えられることである．著者らは勝連トラバーチンをコンクリートと比較できる形で日陰のない平地(草地)に敷設し，表面温度，地中熱伝導，放射収支およびその他の気象要素の長期モニタリングを行った．また，色調を合わせた高反射性塗料を塗布したコンクリートとの間で類似の比較実験を行った．それらの結果，勝連トラバーチンの高い表面反射率および熱容量などの特異な物理特性が都市熱環境改善への有益性をもたらしていることがあきらかとなった．

キーワード： トラバーチン，ヒートアイランド，舗装材料，熱収支，熱環境

1. INTRODUCTION

A special material for pavement, "Katsuren Travertine" is produced from limestone (*foraminifera* rich) mined enough around Katsuren Town in the Okinawa Island. One advantage of "Katsuren Travertine" as a paving material comparing with others like concrete is saving the increase of surface temperature by solar radiation. To apply this "Katsuren Travertine" on pavement in urban area for thermal environmental mitigation, the saving mechanism has to be quantitatively evaluated.

2. OUTLINE OF MONITORING

The authors have settled "Katsuren Travertine" with the size of 5m x 5m and comparative normal concrete blocks on a flat grassland with no sunshade in the National Institute for Environmental Studies (Onogawa, Tsukuba, Ibaraki, Japan), and monitored surface temperature, conductive heat flux, and radiation balance (Fig. 1, Fig. 2, Fig. 3, Fig. 4). Moreover, a DAVIS weather station was settled near both blocks for measuring representative meteorological factors at the monitoring site (Fig. 5). The temperature measured by DAVIS is defined to "background temperature." This observation was conducted from 0:00 July 10th to 23:00 September 8th in 2003.
18 days out of 61 days were selected as typical fine day under the conditions of daily precipitation is 0 mm, maximum radiation an hour is equal or over 500 W/m^2, and total daily radiation is equal or over 4000 Wh/m^2.



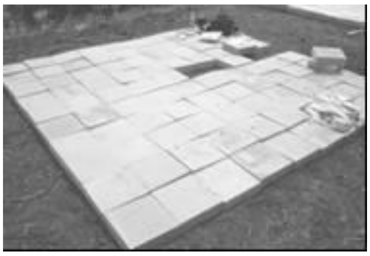


Fig. 1 Outlook of monitoring site (left)
Fig. 2 Surface of "Katsuren Travertine" (1m x 1m unit located at the center of specimen) (middle)
Fig. 3 Concrete blocks (5m x 5m) as a control run (right)

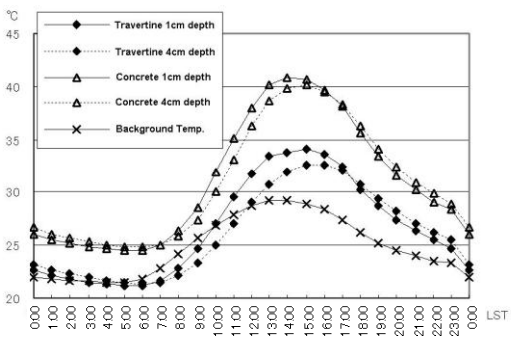
 

Fig. 4 Measurement of radiation balance above the specimens (left)

Fig. 5 Locations of two specimens and a DAVIS weather station (right)

3. MONITORED RESULTS ON CONCRETE AND TRAVERTINE

Fig. 7 shows that heat flux (*G*) of concrete, from bottom of specimen to soil, changes to positive after 8:00 as heat of solar radiation is carried from surface to bottom of specimen. This heat flux changes to negative again when temperature at the bottom of specimen becomes lower than soil temperature after 19:00. On the other hand, heat flux (*G*) of “Katsuren Travertine” shows only small diurnal variability. During daytime, increase in temperature of “Katsuren Travertine” is small and heat flux (*G*) from bottom of specimen to soil is also small. Then, it is considered that soil under the concrete storages large heat and its heat returns to the concrete again at night.



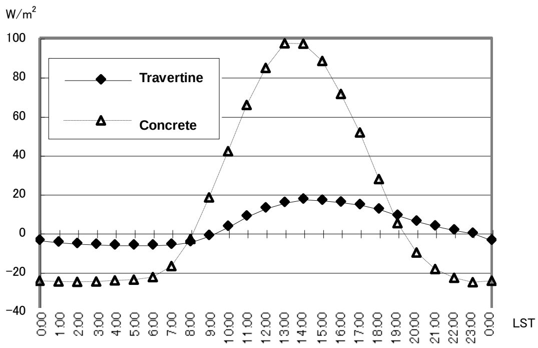


Fig. 6 Comparison of temperatures inside specimens in fine days (left)

Fig. 7 Comparison of conductive heat flux at the bottom of specimens in fine days (right)

Sum of upwarding sensible heat flux from specimens to air (*H*) and heat storage inside specimens (*Q*) is considered to be equal to net radiation balance (R_n) deducted conductive heat flux at the bottom of specimens (*G*) as shown in Eq. (1) under the assumption of no heat transportation to horizontal direction and no latent heat transportation exist around the specimens. This is called R_n -*G*.

$$H + Q = R_n - G \quad (1)$$

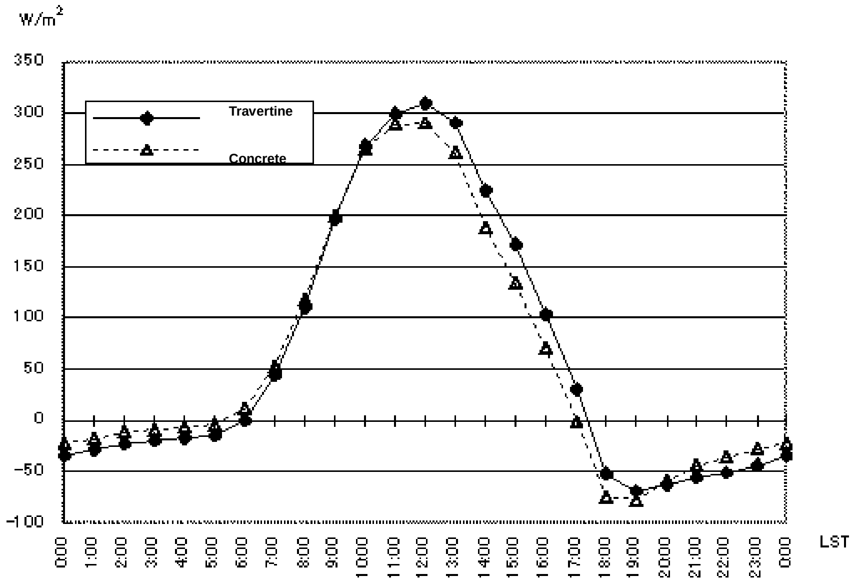


Fig. 8 Comparison of R_n -G in fine days

Compared to "Katsuren Travertine", concrete receives larger heat, approximately 40-50 W/m^2, as net radiation (R_n) and conducts larger heat flux (G), approximately 70-80 W/m^2, from bottom of specimen to soil from 12:00 to 14:00. As this result, shortage of energy (R_n -G), approximately 20-35 W/m^2, which should be divided into upwarding sensible heat flux from specimen to air (H) and heat storage inside specimen (Q), is considered (Fig. 9). On the other hand, upwarding sensible heat flux (H) from concrete is expected to be larger than that from "Katsuren Travertine" from comparison between temperatures inside specimens at 1cm depth, which is considered to be close to the surface temperature of specimens, and "background temperature." Moreover, direction of heat flux at the upper part of the specimens, which is estimated from temperatures at two depths of the specimens, is considered to be downward during these hours (Fig. 6). Therefore, during these hours, heat storage inside specimen (Q) of "Katsuren Travertine", which has small conductive heat flux (G), is expected to increase. Then, "Katsuren Travertine" is considered to have larger heat storage (Q) than concrete. However, temperature inside "Katsuren Travertine" is lower than that of concrete. This result shows heat capacity of "Katsuren Travertine" is considered to be larger than that of concrete.

Since "Katsuren Travertine" has small conductive heat flux (G) compared with R_n -G during nighttime, its heat storage (Q) seems to decrease as heat flux at the upper part of the specimen becomes upward, and surface temperature also seems to decrease referring to the change in temperature inside specimen at 1cm depth. Because of the relation with "background temperature", upwarding sensible heat flux (H) from the surface of "Katsuren Travertine" is lower than that of concrete and its R_n -G changes slowly. "Katsuren Travertine", therefore, seems to radiate energy storaged inside specimen (Q), which is accumulated during daytime, as upwarding long wave radiation.

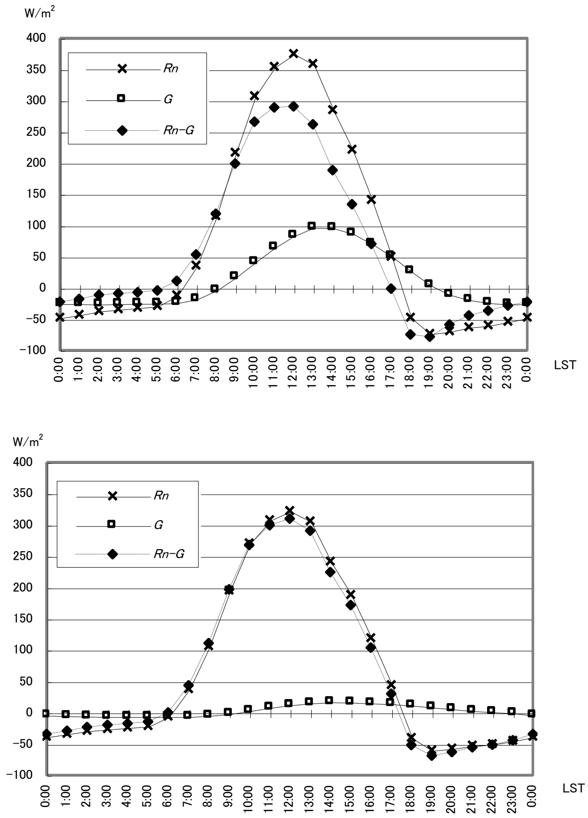
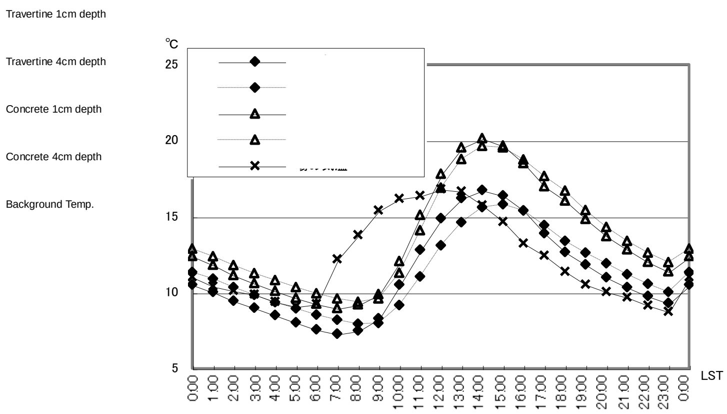


Fig. 9 Comparison of net radiation balance (R_n), conductive heat flux at the bottom of specimens (G) in fine days, R_n -G

Concrete (upper)   Travertine (lower)

4. COMPARATIVE MONITORING ADJUSTING REFLECTION RATE OF CONCRETE TO TRAVERTINE'S

For investigating the mechanism of mitigation effect on surface temperature increase of specimen, the high-albedo painting which fitted a color tone and a reflection rate to "Katsuren Travertine" were applied on the surface of the concrete. This observation was conducted from 0:00 November 1st to 23:00 November 26th in 2003. Relationship between both specimens revealed in summer observations is confirmed in this observation even though order of values like temperature is different. Then, the authors concluded that not only high reflectance but also thermal physical factors like heat capacity of “Katsuren Travertine” have potential to mitigate urban thermal environment.



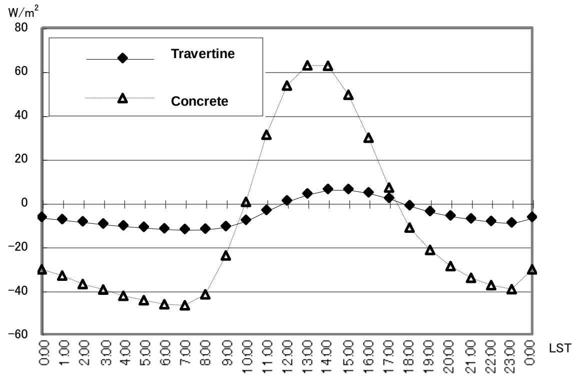


Fig. 10 Comparison of temperatures inside specimens in fine days (upper)

Fig. 11 Comparison of conductive heat flux at the bottom of specimens in fine days (lower)

Both figures show the results in case of adjusting reflection rate of concrete to Travertine’s.

5. CONCLUSIONS

A special material for pavement, “Katsuren Travertine” is produced from limestone (*foraminifera* rich) mined enough around Katsuren Town in the Okinawa Island. One advantage of “Katsuren Travertine” as a paving material comparing with others like concrete is saving the increase of surface temperature by solar radiation. To apply this “Katsuren Travertine” on pavement in urban area for thermal environmental mitigation, the saving mechanism has to be quantitatively evaluated. The authors have settled “Katsuren Travertine” with the size of 5m x 5m and comparative normal concrete blocks on a flat grassland with no sunshade, and monitored surface temperature, conductive heat flux, radiation balance, and other meteorological factors from July to November in 2003. As another comparative study, the high-albedo painting which fitted a color tone and a reflection rate to “Katsuren Travertine” were applied on the surface of the concrete. The authors concluded the high reflectance and thermal physical factors like heat capacity of “Katsuren Travertine” have potential to mitigate urban thermal environment. More examination is necessary about the physiological impact for pedestrians of the application.

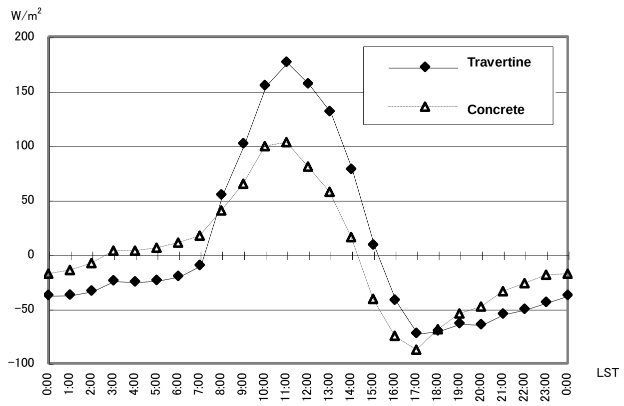


Fig. 12 Comparison of R_n -G in fine days

Result in case of adjusting reflection rate of concrete to Travertine’s

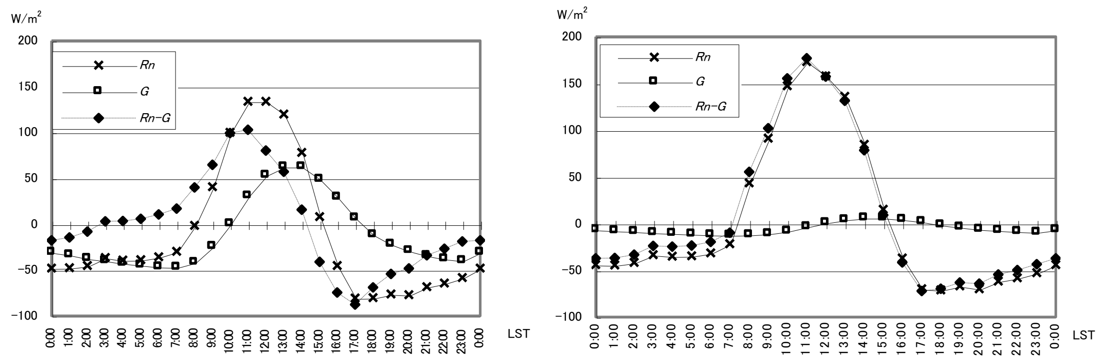


Fig. 13 Comparison of net radiation balance (R_n), conductive heat flux at the bottom of specimens (G) in fine days, R_n -G

Concrete (left) Travertine (right)

Result in case of adjusting reflection rate of concrete to Travertine’s